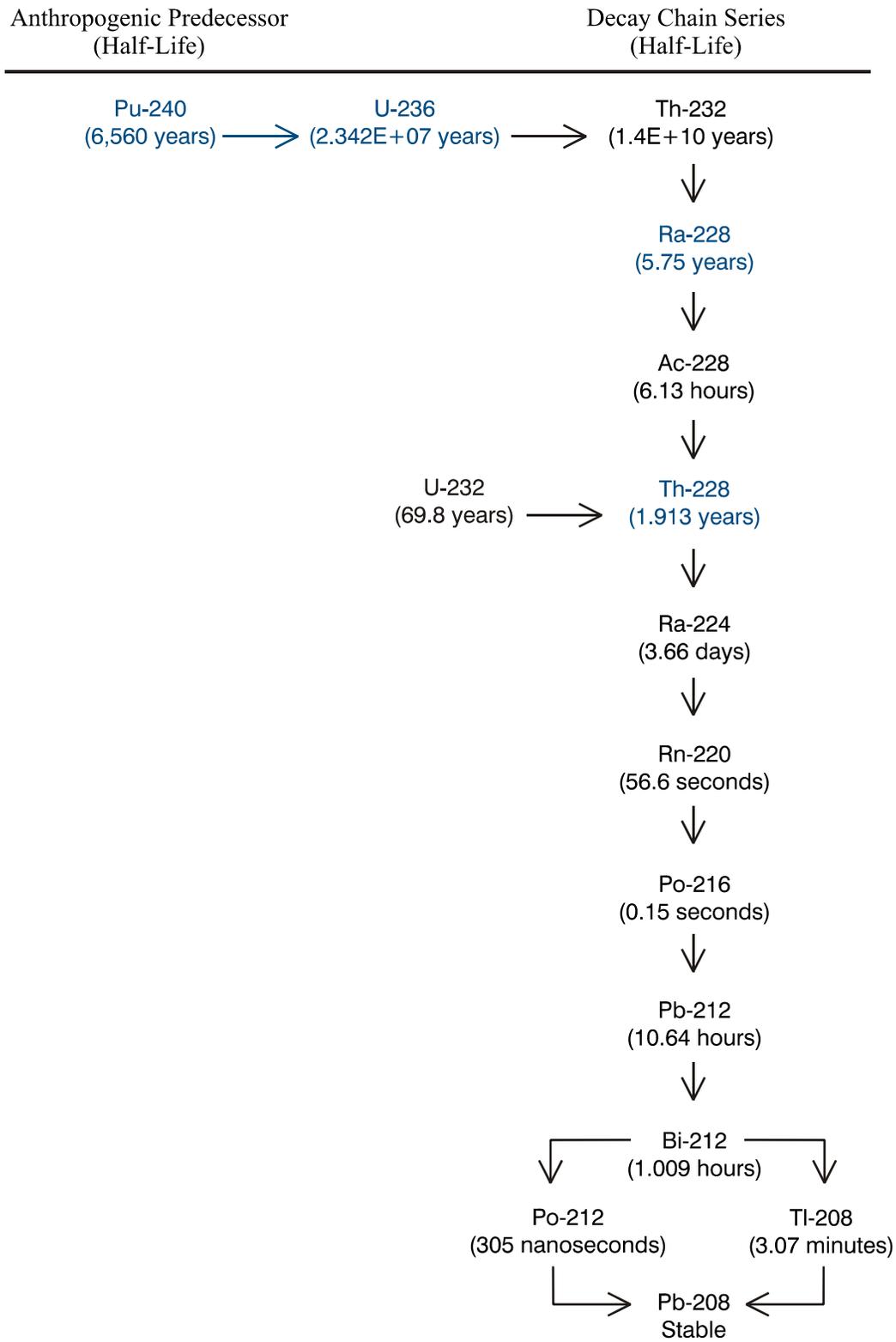


4.1.2.2 Ingrowth. Waste in the SDA contributes radionuclides to the source-term inventory either directly through disposals (see Table 4-2) or over time through ingrowth (i.e., incremental accumulation of daughter products generated by decay of the parent). Of the 20 radionuclides listed in Table 4-2, 13 of them are members of four decay chains: Am-241, Np-237, Pb-210, Pu-239, Pu-240, Ra-226, Ra-228, U-233, U-234, U-235, U-236, and U-238. In three of the decay-chain series, anthropogenic predecessors decay into members of naturally occurring decay series, named after the initiating natural nuclide: the thorium, uranium, and actinium series. A fourth decay chain, the neptunium series, does not occur naturally.

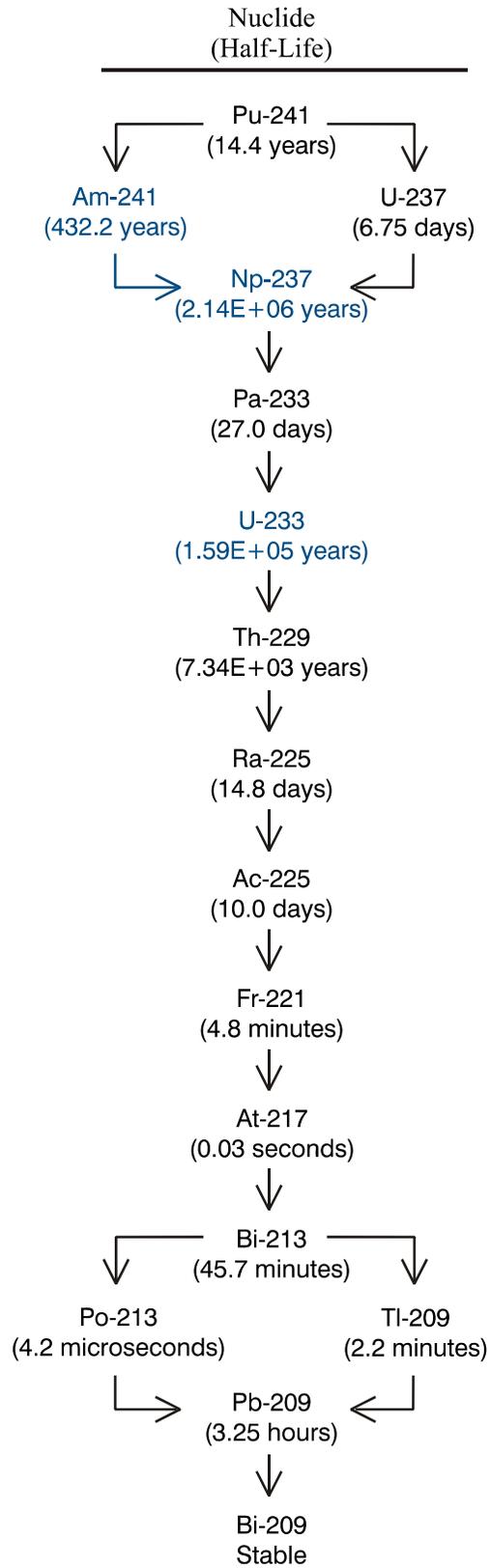
In some cases, the presence of one contaminant can be inferred by the presence of another because decay is predictable. Decay-chain members for the four series are listed in their decay sequence in Figure 4-30 for the thorium series, Figure 4-31 for the neptunium series, Figure 4-32 for the uranium series, and Figure 4-33 for the actinium series, as documented by Shleien (1992). Two nuclides in the same row of the figure indicate that both can emanate from the parent nuclide listed above. Typically, the first decay product is common, and the second is rare. The exception is the Po-211 and Tl-207 pair near termination of the actinium series. Half-lives also are listed. The contaminants of potential concern identified in Section 3.4 and discussed in this report are shaded blue in Figures 4-30 through 4-33.

Inventories of radioactive contaminants of potential concern are affected over time as parent nuclides decay and progeny accumulate. The shorter the half-life, the more significant these changes can be. Throughout Section 4, inventories are reported at the time of disposal with two exceptions (i.e., Am-241 and U-238). All Pu-241 inventories were converted into Am-241, and all Pu-242 inventories were converted to U-238. Ingrowth amounts were calculated by assuming that contributing parent isotopes, Pu-241 and Pu-242, completely transform into their progeny, Am-241 and U-238, respectively.



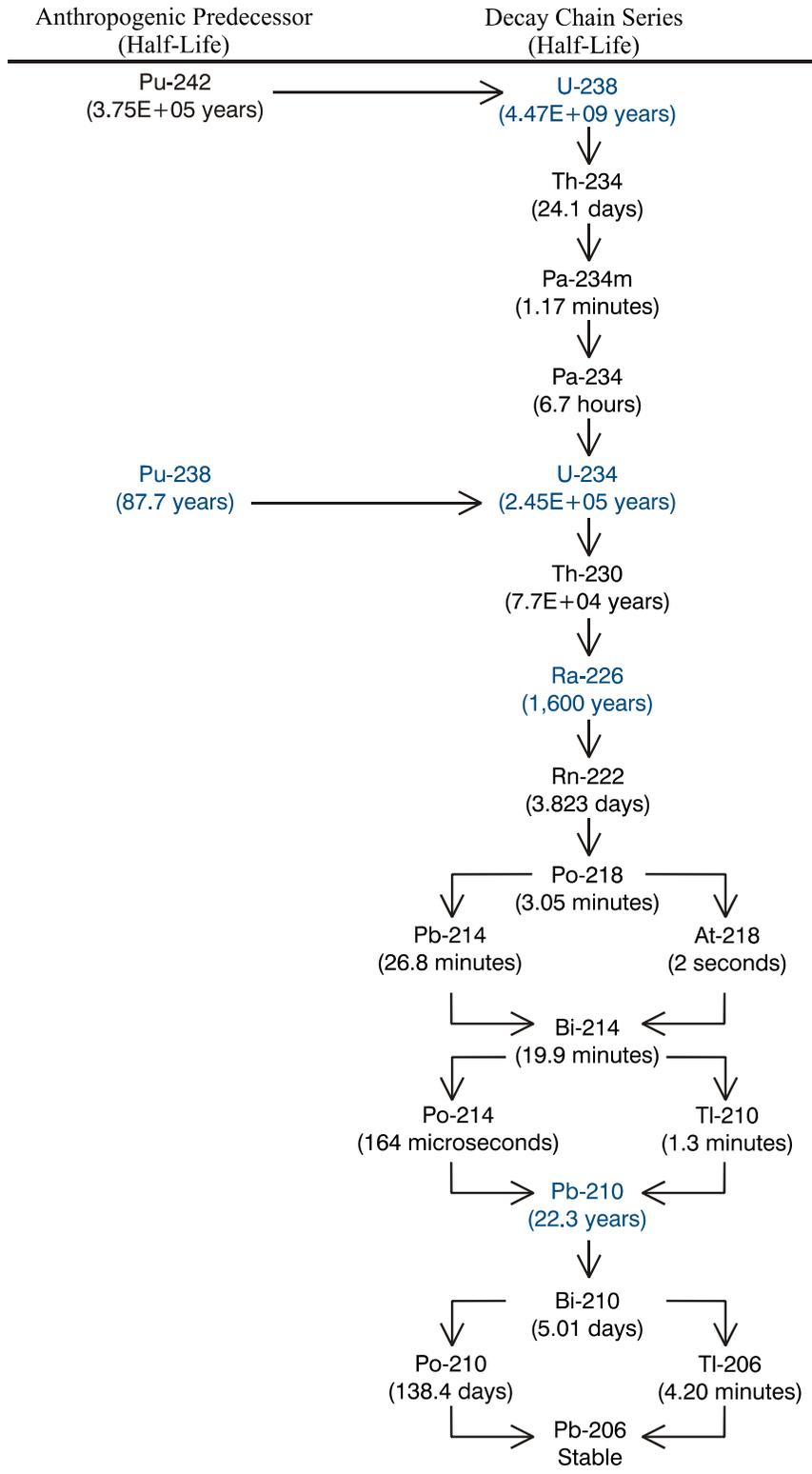
G1555-01

Figure 4-30. Decay chain for the thorium decay series, including anthropogenic predecessors from weapons manufacturing and reactor operations; contaminants of potential concern are shown in blue.



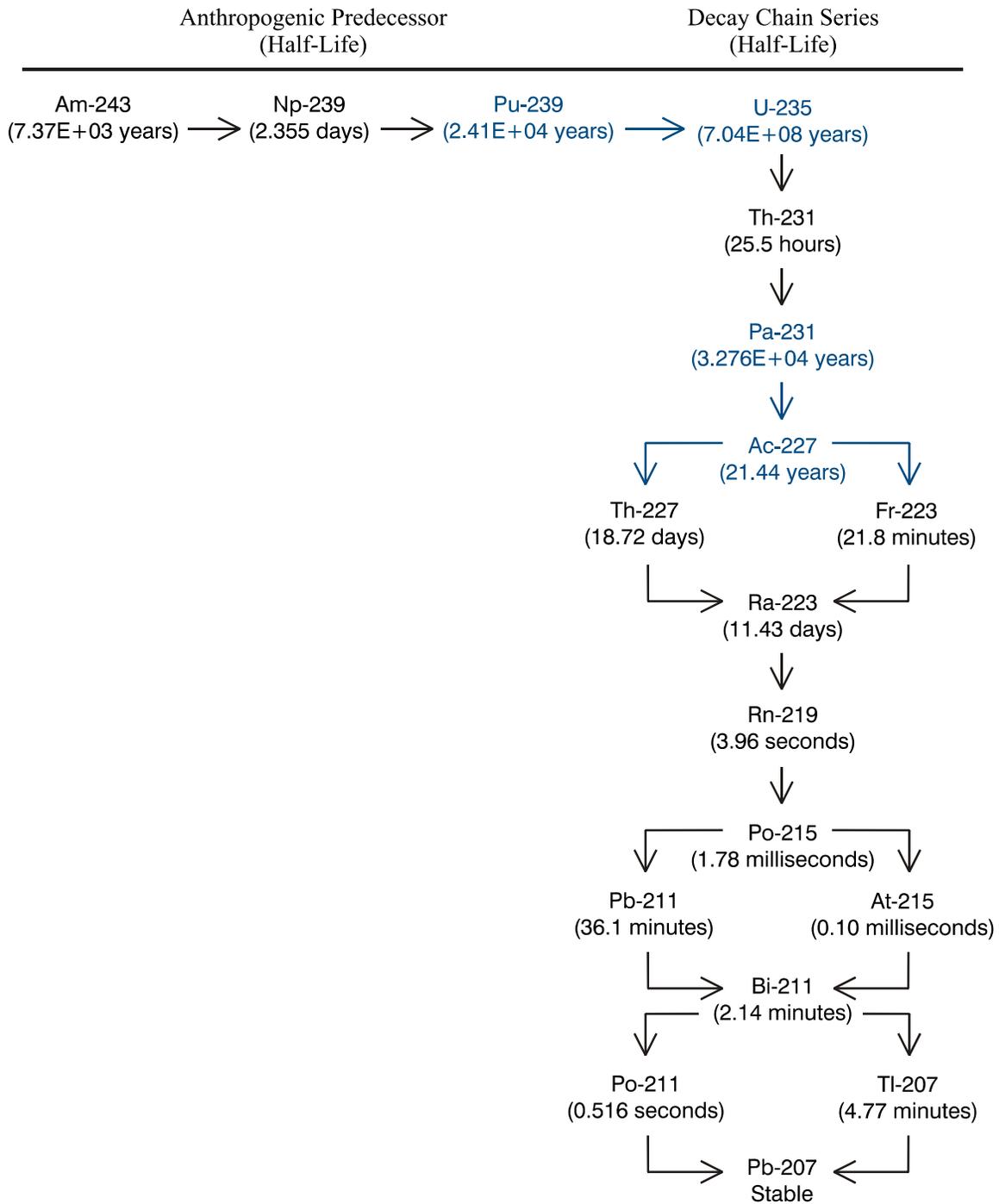
G1555-02

Figure 4-31. Decay chain for the neptunium series; contaminants of potential concern are shown in blue.



G1555-03

Figure 4-32. Decay chain for the uranium series, including anthropogenic predecessors from weapons manufacturing and reactor operations; contaminants of potential concern are shown in blue.



G1555-04

Figure 4-33. Decay chain for the actinium series, including anthropogenic predecessors from weapons production and reactor operations; contaminants of potential concern are shown in blue.

4.1.2.3 Nuclear Logging of the Waste Zone. Nuclear logging data were gathered to provide information on the physical, chemical, and radiological conditions within the SDA waste zone. Beginning in December 1999, 142 cased steel probe holes were installed in waste-bearing portions of Pits 4, 5, 9, and 10 of the SDA (see Figure 4-34). Installing Type A probes provides the means for in situ characterization of subsurface soil and waste material by lowering nuclear logging tools into the probe hole. The nuclear logging tools measure soil moisture, gamma radiation flux, neutron radiation flux, and chemical characteristics within the soil and waste surrounding the probe holes. In some cases, data were interpreted to estimate radionuclide concentrations based on several simplifying assumptions (e.g., homogeneous media). These estimates are qualitative and can be used only to assess relative concentrations, not absolute concentrations (see Section 3.6). Table 4-8 gives a brief description of the logging tool suite. Section 3.6 contains more information about Type A probes.

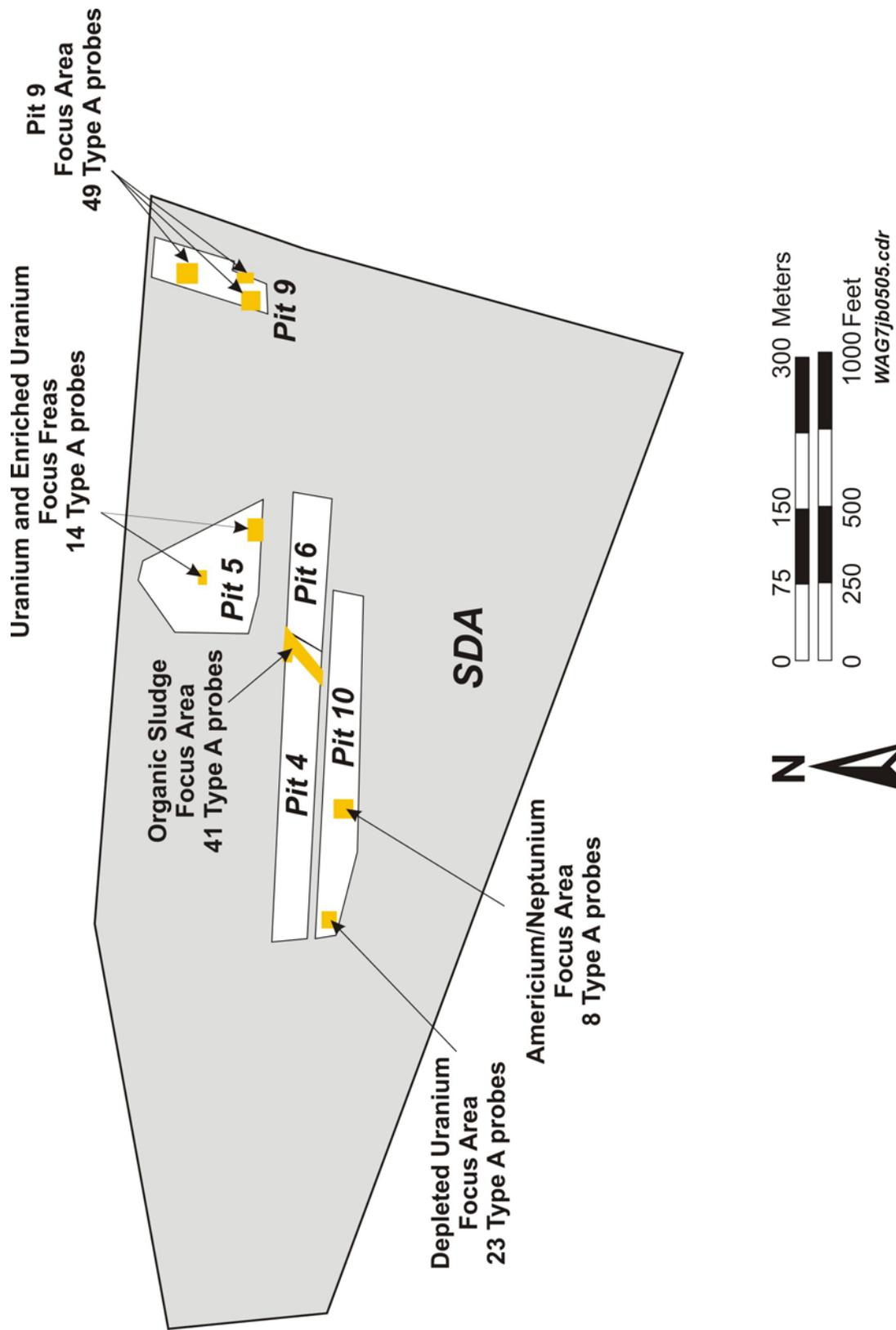


Figure 4 34. Type A probes from which nuclear logging data were obtained.

Table 4-8. Description of Type A probe logging tools.

Tool	Detector Type	Detection Capabilities
Spectral gamma log	Germanium gamma detector	Gamma-emitting radionuclides
Passive neutron log	He-3 neutron detector	Fissile radionuclides
Moisture log	Americium-beryllium neutron source combined with neutron detector	Total hydrogen
Activated gamma (n gamma) log	Cf-252 neutron source combined with germanium gamma detector	High neutron-capture cross-section elements (e.g., chlorine, iron, silicon, and calcium)
Azimuthal spectral gamma log	Germanium gamma detector with slotted shield	Rotated in probes to determine direction of maximum gamma flux

4.1.2.4 Waste Zone Monitoring Network. Sets of instrumented probes, either Type B probes or GEOPS (see Section 3.6.3), within specified focus areas provide limited monitoring capability within SDA buried waste. The network consists of instrumented probes that were installed and completed within the waste zone. Unlike other monitoring locations adjacent to or beneath buried waste, probes completed within the waste provide data uncompromised by outside influences. In particular, lysimeters and vapor ports are providing soil-moisture and vapor samples that have been in direct contact with waste and interstitial soil in the waste zone. However, though these data provide insight into current conditions within the waste, they are not representative of general conditions at the SDA and surrounding environments. Their usefulness in characterizing the SDA is generally to corroborate disposal records (e.g., locations).

Instruments were installed in two series of probes between December 1999 and August 2004 based on locations selected from disposal records and confirmed through logging of Type A probes. Type B probes, including lysimeters, were installed first. Unfortunately, most of the Type B lysimeters were dysfunctional, probably because of damage during installation with a sonic drill rig. Improvements were designed and deployed in a second series of probes. Called GEOPS, the improved instruments are much more effective. Sample volumes are now being obtained and analyzed. As of August 2004, two rounds of samples have been collected. Figure 4-35 illustrates the locations of Type B and GEOPS lysimeters that have produced sample volumes to date. Also, Type B vapor port probes (Section 3.6.1.2) were installed to collect samples from soil vault rows (SVRs) near the beryllium blocks, which are analyzed specifically for tritium and C-14. Section 3.6 provides detailed information about waste zone monitoring focus areas and probes within the SDA.

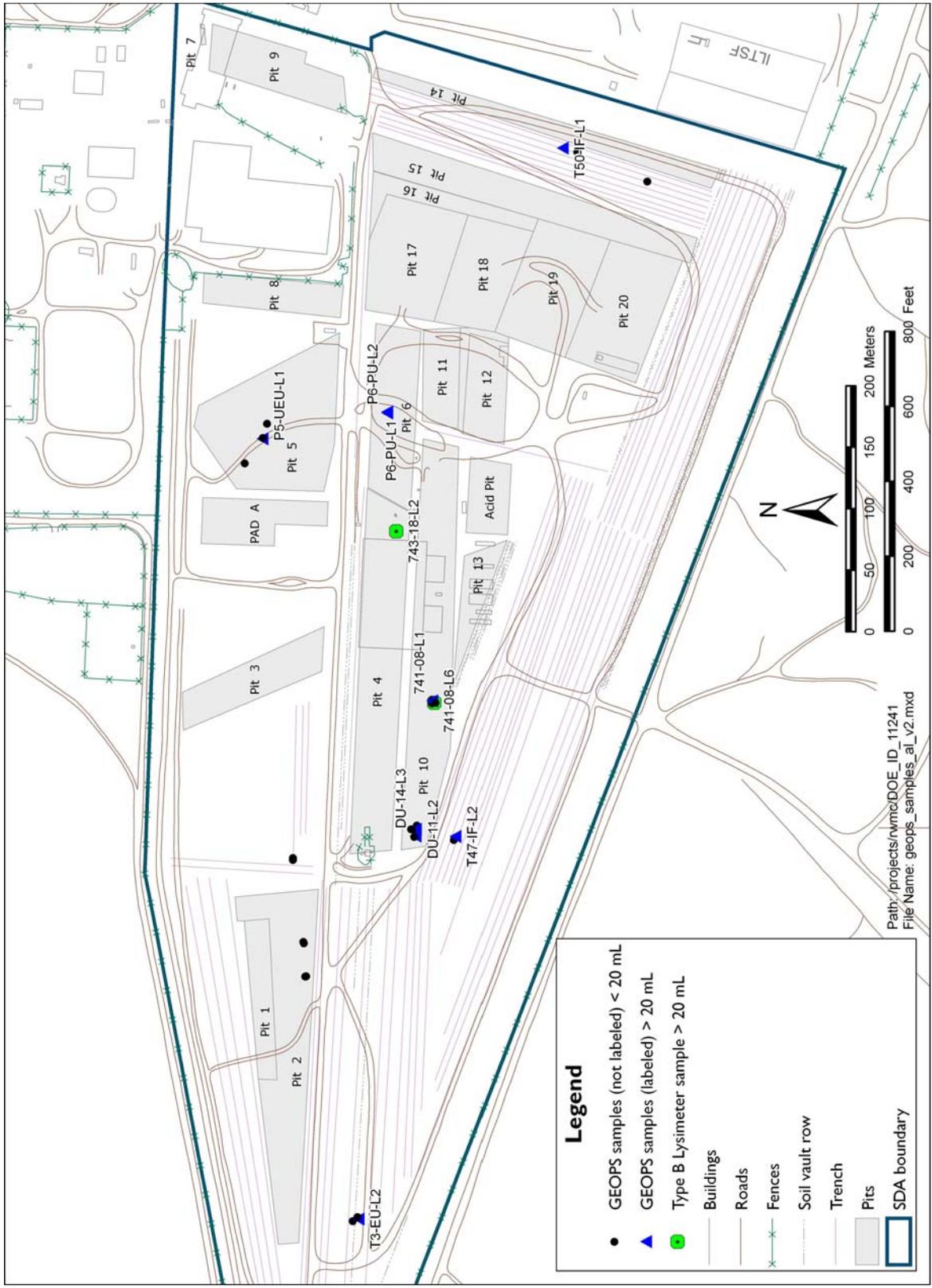


Figure 4-35. Instrumented probes that have collected soil moisture from focus areas in the Subsurface Disposal Area.

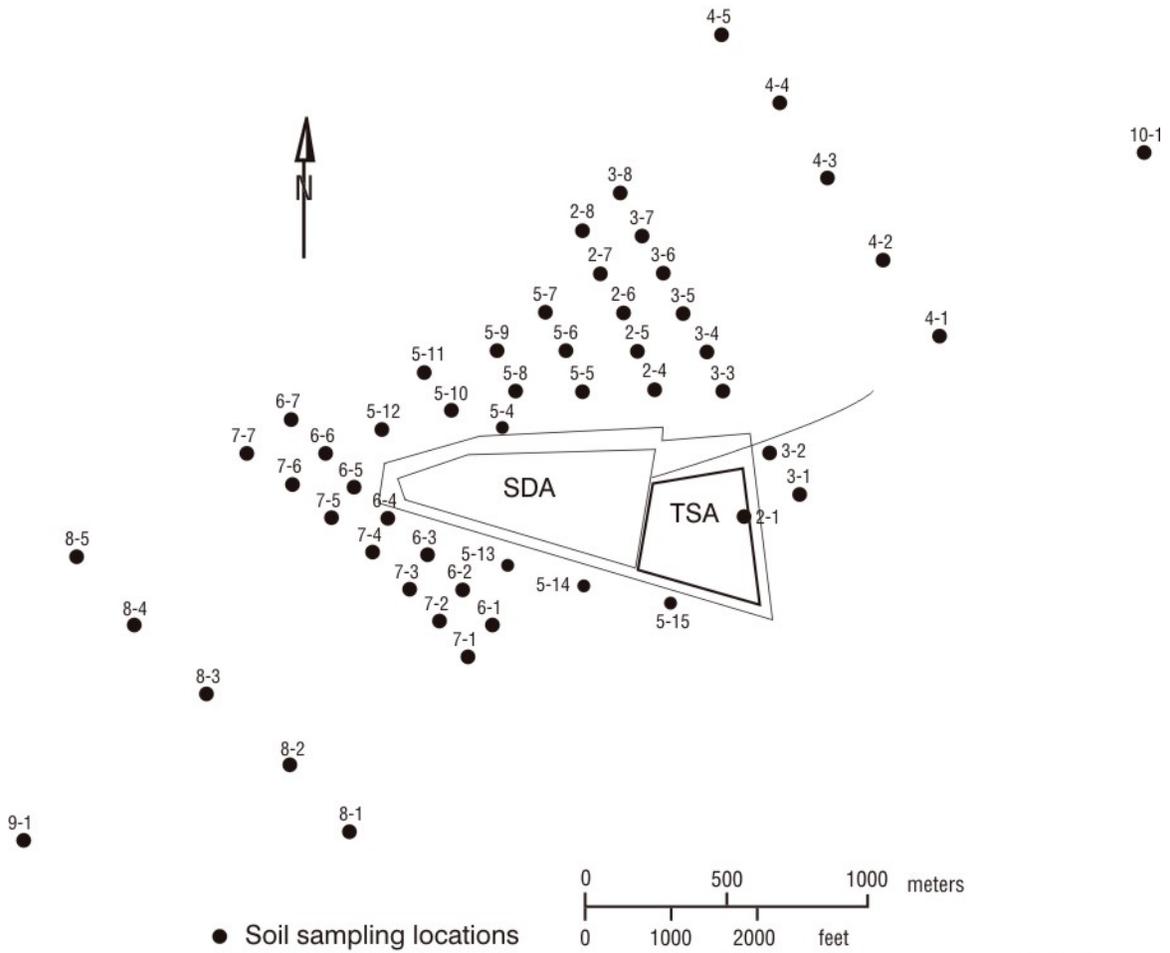
4.1.3 Surface Sample Data

Samples of the SDA overburden, nearby surface soil, surface water run-off, and vegetation in the RWMC area are classified as surface data. Only the top 6 cm (2 in.) of soil is sampled. Because the SDA was recontoured with clean soil several times between 1986 and the mid-1990s, comparing recent surface soil data (1997 to 2004) to data collected before 1997 to assess trends is not meaningful.

All samples are analyzed by gamma spectroscopy, and selected samples based on activity are analyzed using radiochemistry. Surface soil samples are collected around RWMC every 3 years and analyzed by gamma spectroscopy for selected radionuclides. Figure 4-36 shows the locations for RWMC soil samples, with Figure 4-37 showing SDA-specific samples and Figure 4-38 showing locations specific to the Transuranic Storage Area. Figure 4-39 shows the areas where vegetation samples are collected. Vegetation samples are collected annually, with crested wheatgrass and perennials collected in odd years and Russian thistle collected in even years. Surface water run-off samples, if available, are collected quarterly in the locations shown in Figure 4-40.

In 2003, SDA-wide sampling was performed, and soil samples collected from the locations shown in Figure 4-37 were analyzed. In 2004, additional samples were collected outside the SDA at the locations shown in Figure 4-37 and archived to provide a current baseline for the Accelerated Retrieval Project at the Subsurface Disposal Area. Also in 2004, one sample was collected in the Pit 9 area and archived.

RWMC Soil Sampling Grid



G1569-21

Figure 4-36. Surface soil sampling locations around the Radioactive Waste Management Complex.

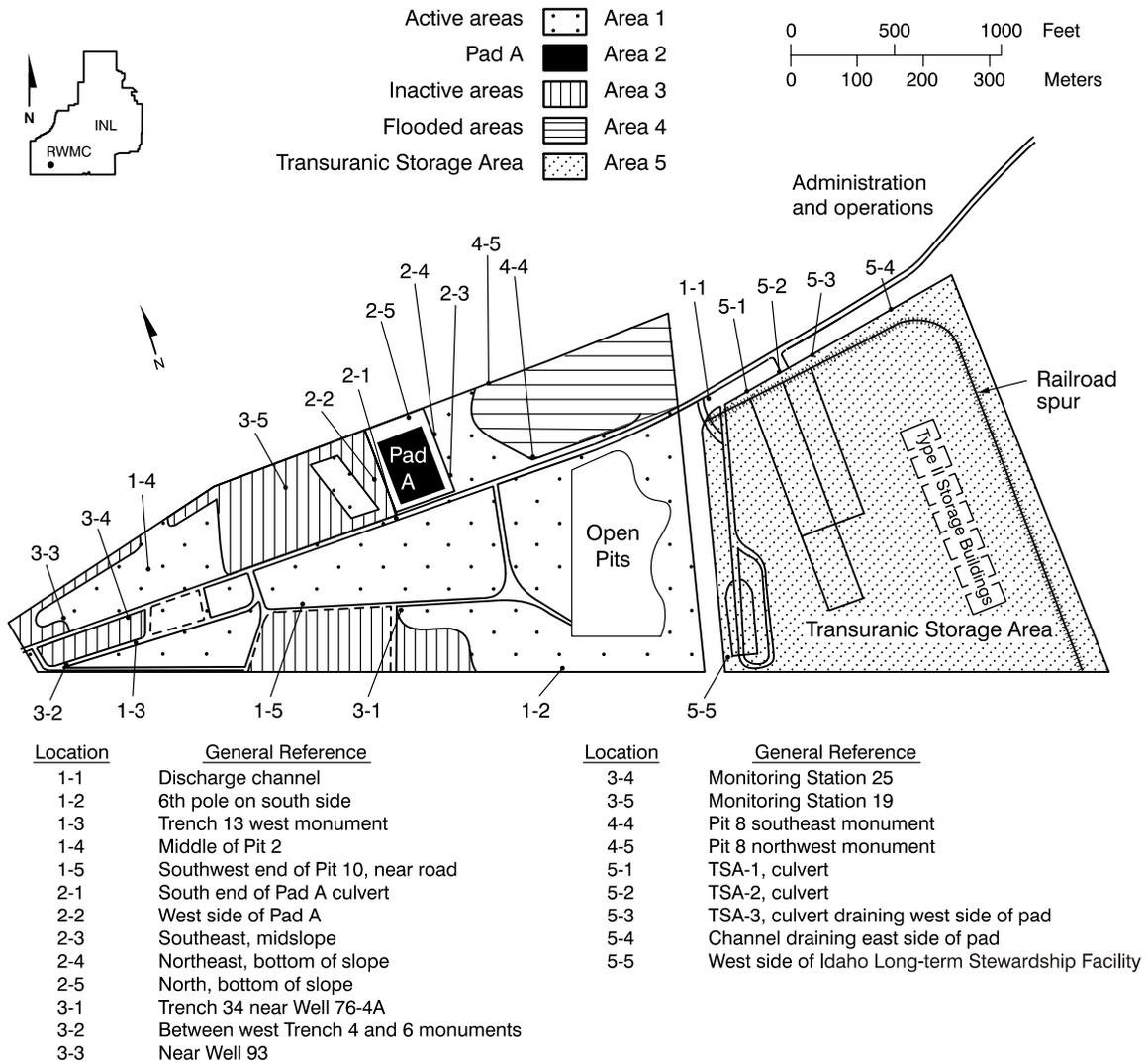
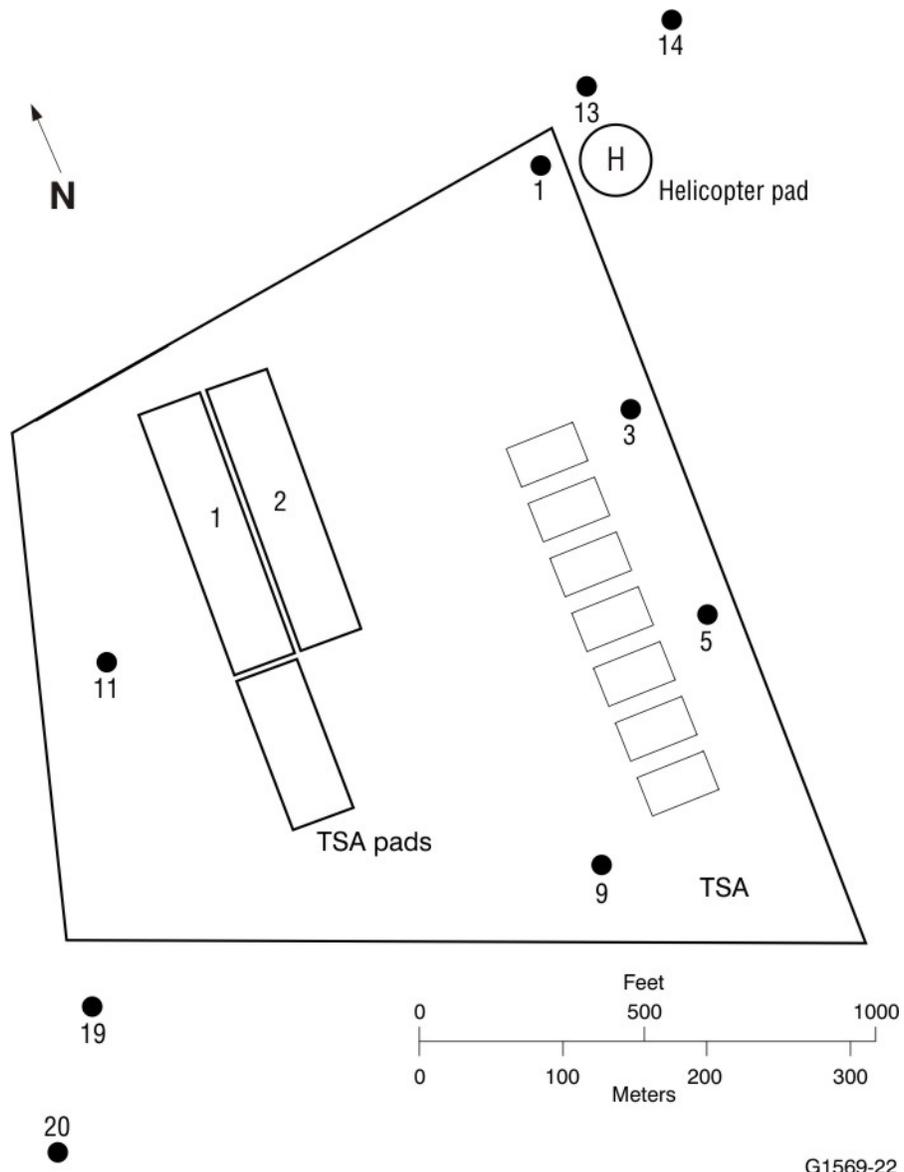


Figure 4-37. Surface soil sampling locations at the Subsurface Disposal Area.

G1569-19



G1569-22

Figure 4-38. Surface soil sampling locations at the Transuranic Storage Area.

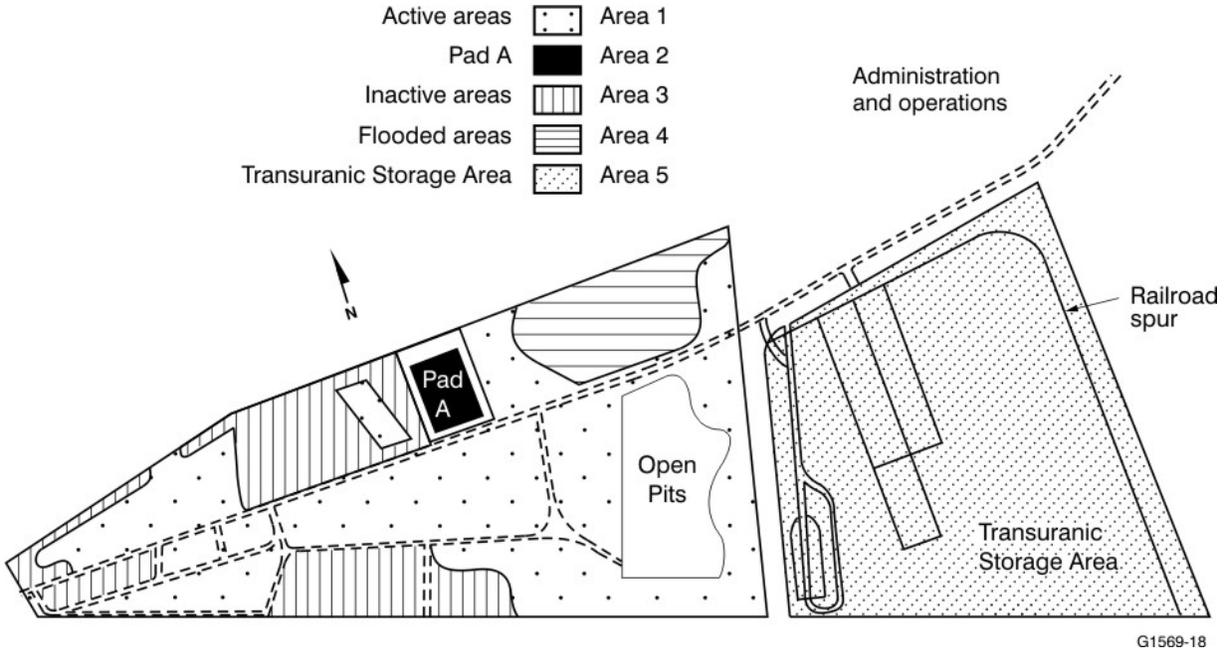


Figure 4-39. Vegetation sampling areas at the Radioactive Waste Management Complex.

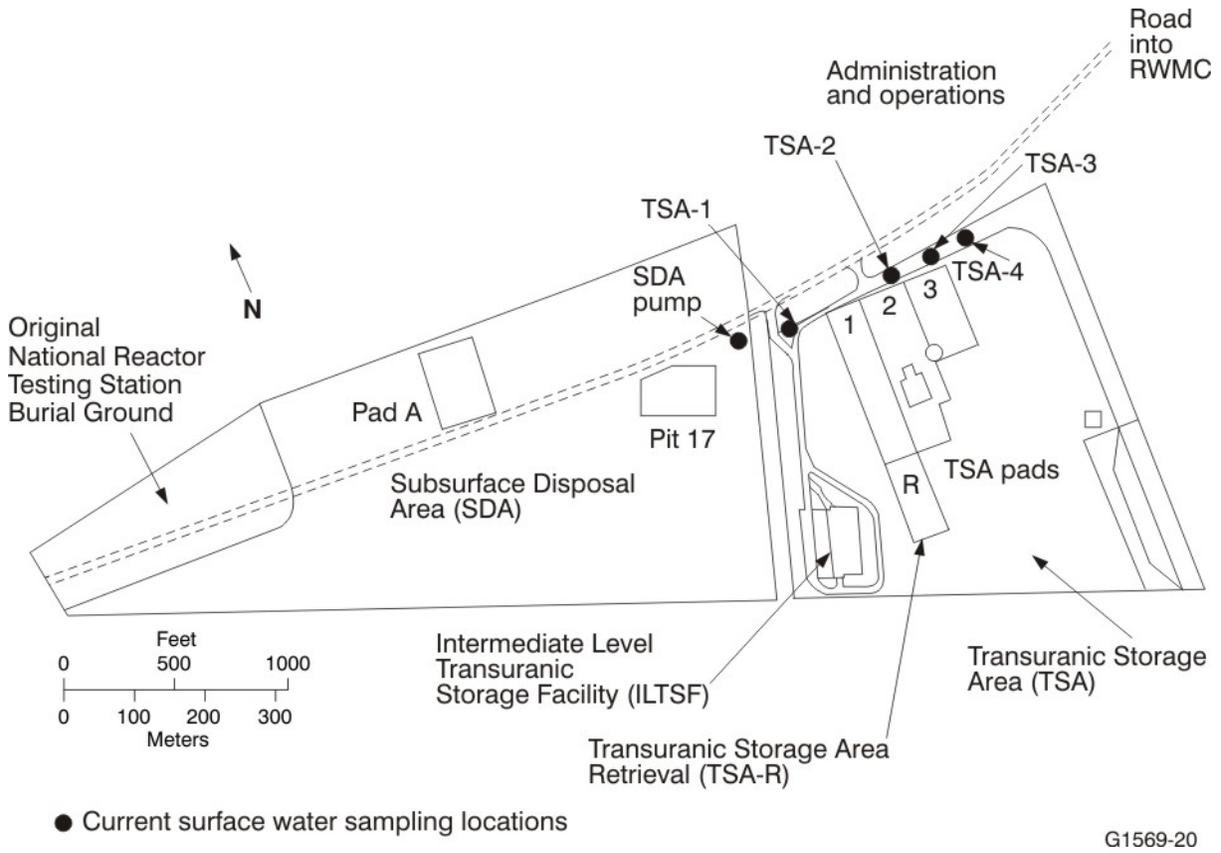


Figure 4-40. Surface water run-off sampling locations at the Radioactive Waste Management Complex.

4.1.4 Vadose Zone Data

The vadose zone is defined as the unsaturated interval between land surface and the aquifer. The sources of data used to describe contaminants in the vadose zone are suction lysimeter samples, perched water samples, vapor samples, and samples of soil and rock from cores.

4.1.4.1 Suction Lysimeter Network. Lysimeter sampling is conducted to characterize soil moisture in the vadose zone. A network of suction lysimeters at RWMC allows repeated sample collection from sediment near buried waste and from the underlying interbeds. Though the first lysimeter samples were collected at RWMC in 1985 (Hubbell et al. 1985), routine lysimeter sampling did not begin until 1997. Currently, lysimeter sampling is conducted quarterly in accordance with the Second Addendum to the Work Plan (Holdren and Broomfield 2004).

Small volumes of soil moisture, typically 0 to 300 mL, are usually obtained from lysimeters, and 50 mL of that total volume is generally allotted for each separate analysis. Detection limits vary with the sample volume available for analysis. Detection limits increase (i.e., are less sensitive) as sample volumes decrease because of the difficulty associated with precision measurement of small amounts of sample matrix. When soil is relatively dry, a soil-moisture sample cannot be collected from the lysimeter. Analyses are prioritized to obtain the most essential data first.

Results from soil-moisture analyses are evaluated against one or more of the comparison concentrations listed in Table 4-1 and are discussed by depth interval as follows:

- Shallow vadose zone depths ranging from 0 to 10.9 m (0 to 35 ft) (see Figure 4-41)
- Intermediate interval from 10.9 to 42.7 m (35 to 140 ft), corresponding roughly to the interval between the A-B and B-C interbeds (see Figure 4-42)
- Deep vadose zone depths greater than 42.7 m (140 ft), corresponding to the vadose zone beneath the B-C interbed down to the aquifer (see Figure 4-43).

4.1.4.2 Perched Water Sampling with a Bailer. Perched water can form in isolated lenses above the sediment comprising the B-C and C-D interbeds. Samples from the deep vadose zone perched water above the C-D interbed are obtained with a bailer from Wells USGS-92 and 8802D. Well USGS-92 was installed in 1972 and Well 8802D in 1988. These perched water wells have slow recharge rates and thin layers of water, often limiting the volume of water sample that can be collected in the bailer. Generally, samples can be collected at Well USGS-92, but success is sporadic at Well 8802D.

4.1.4.3 Core Sampling. Nine core investigations were conducted at RWMC between 1971 and 2000 by USGS (1971 to 1972), U.S. Department of Energy (DOE) (1975), and various Idaho National Laboratory (INL) Site contractors (1976 to 1977, 1978, 1979, 1986 to 1987, 1993, 1994, and 1999 to 2000). Cores were extracted from numerous locations around RWMC (see Figure 4-44). Many cores extended to the aquifer, with several depth intervals per core targeted for analyses. Core results are compared with soil RBCs (see Table 4-1).

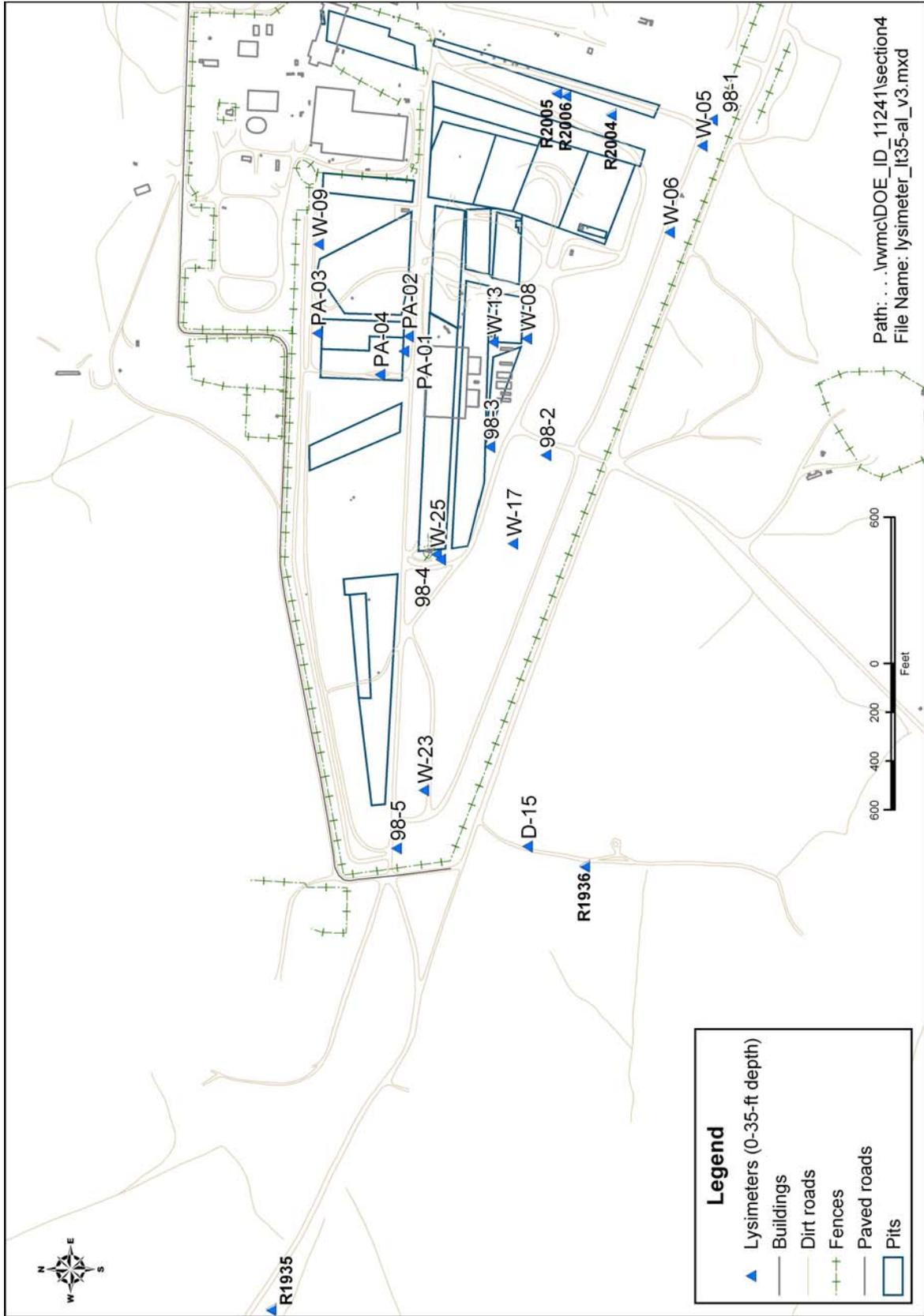


Figure 4-4.1. Shallow-depth lysimeters located at depths from 0 to 35 ft.

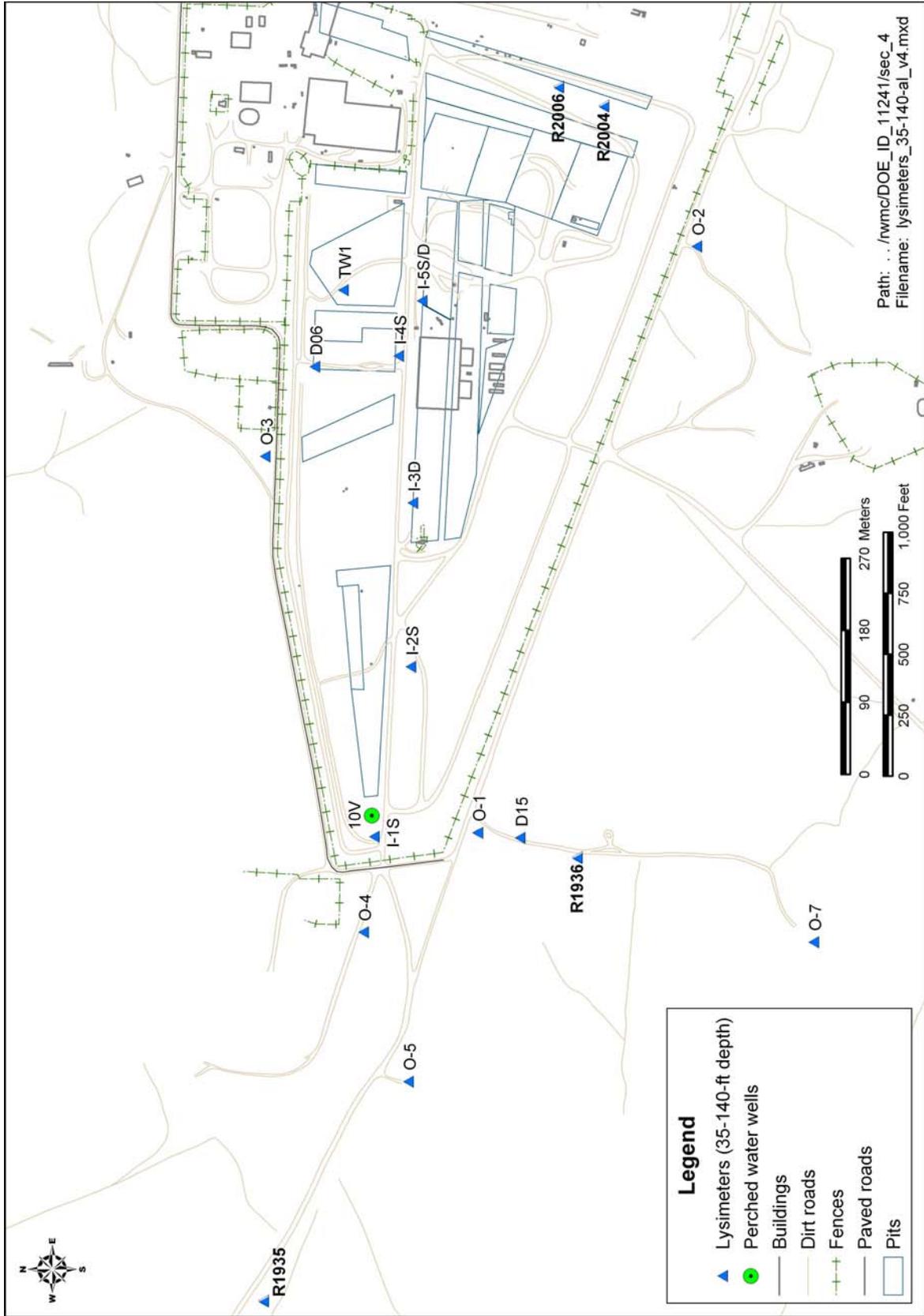


Figure 4-42. Lysimeters located in the intermediate-depth vadose zone at depths from 35 to 140 ft.

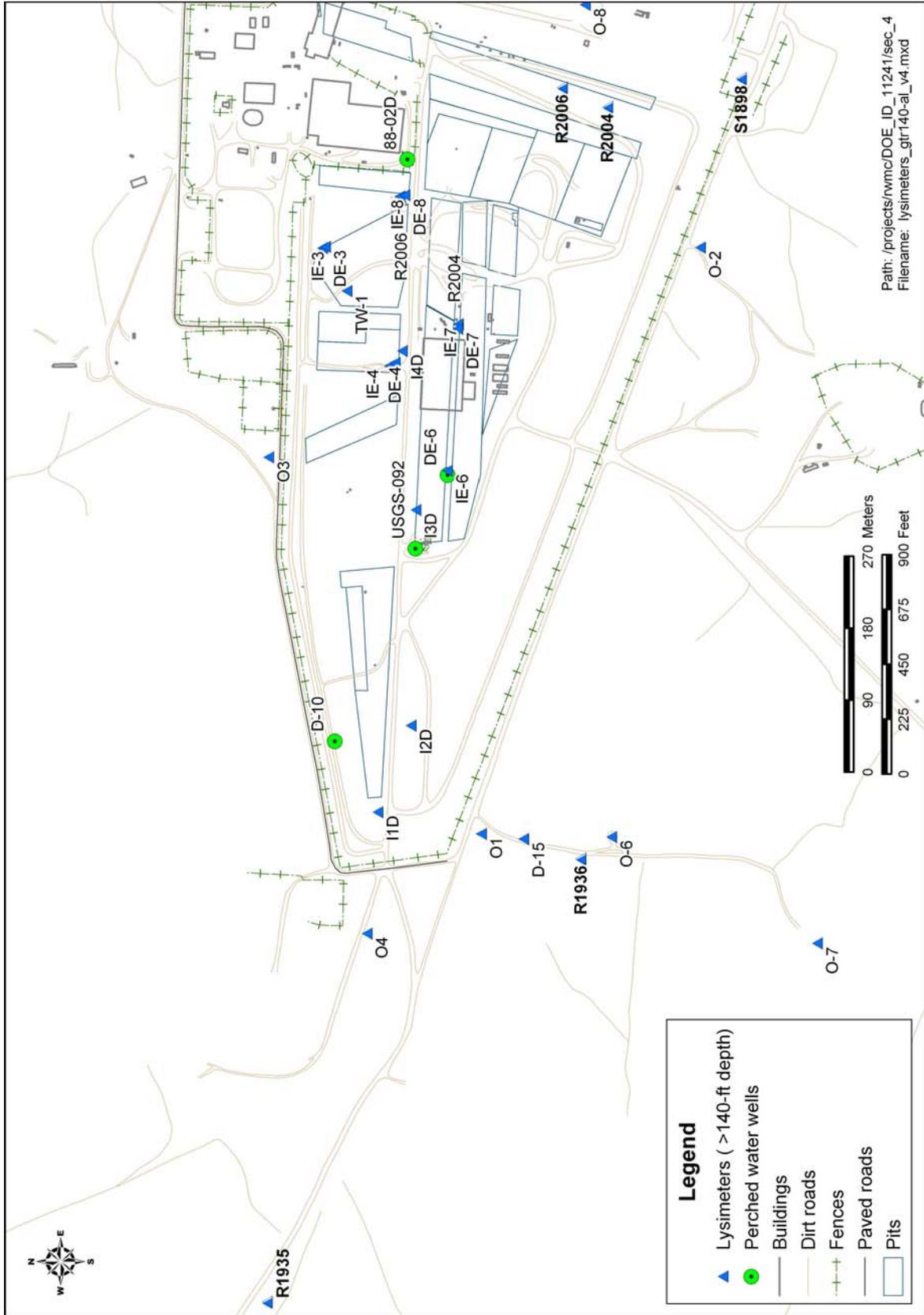


Figure 4-43. Lysimeters located in the deep vadose zone at depths greater than 140 ft.

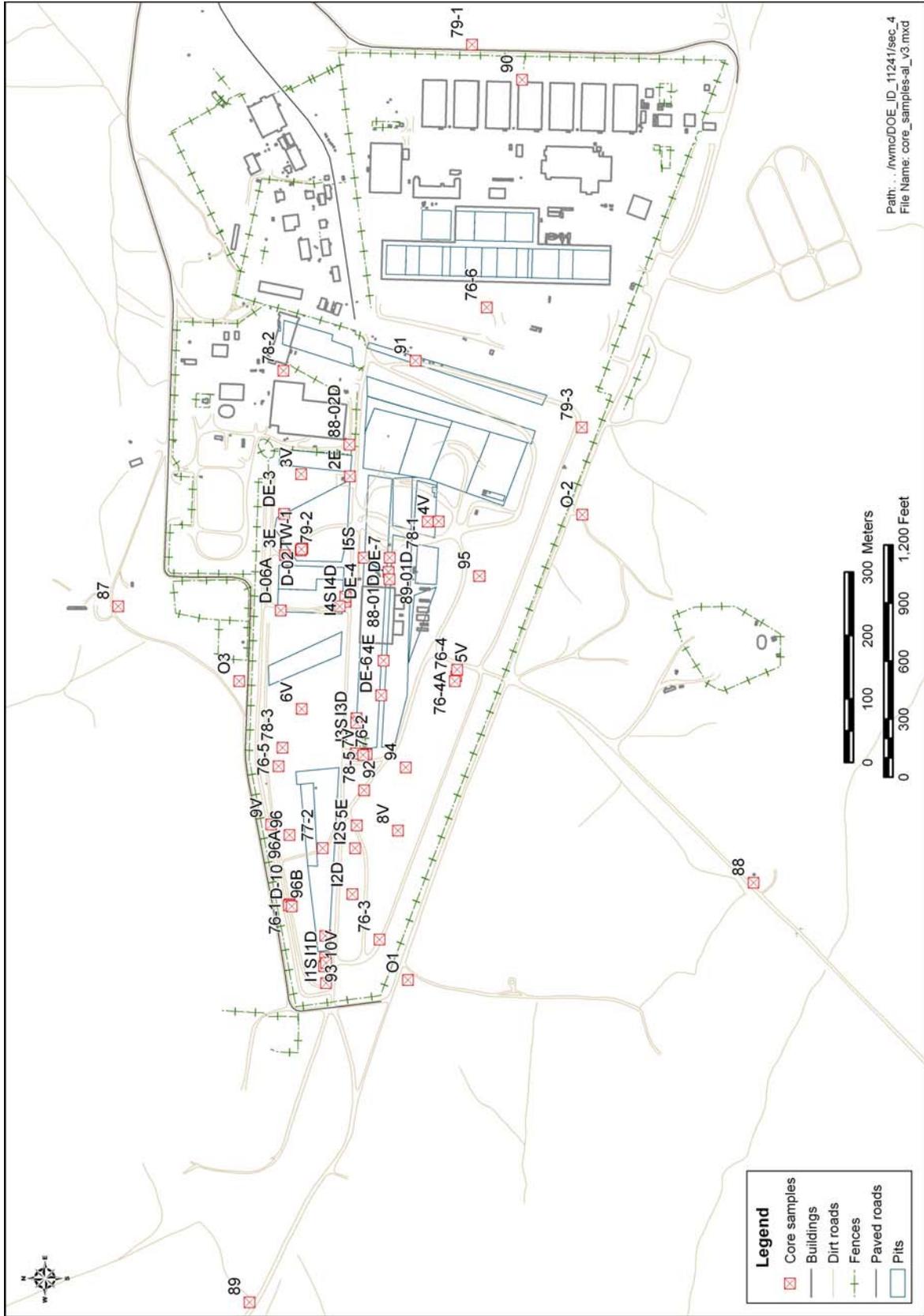


Figure 4-44. Locations of core sample extractions in the Radioactive Waste Management Complex.

Additional cores, from the B-C and C-D sedimentary interbeds, were obtained between November 2002 and March 2003. Core samples were collected directly below areas in the SDA known to contain significant inventories of contaminants, specifically from Wells DE-3, DE-4, DE-6, DE-7, and DE 8 (see Figure 4-44). The samples were analyzed for Tc-99, I-129, U-234, U-235, U-238, Np-237, Pu-238, Pu-239/240, and Am-241. Samples also were analyzed to determine geochemical and hydrological properties. Geochemical properties included mineralogy composition, exchangeable cations, cation-exchange capacity, extractable iron, aluminum and manganese, and surface area. Hydrologic properties included hydraulic conductivity, porosity, moisture characteristics, particle size, water content, and dry bulk density. No radionuclide contaminants were detected above soil background concentrations, except for U-235 in Well DE-4. The geochemical and hydrological properties were similar to previous interbed analysis results (Koeppen et al. 2005).

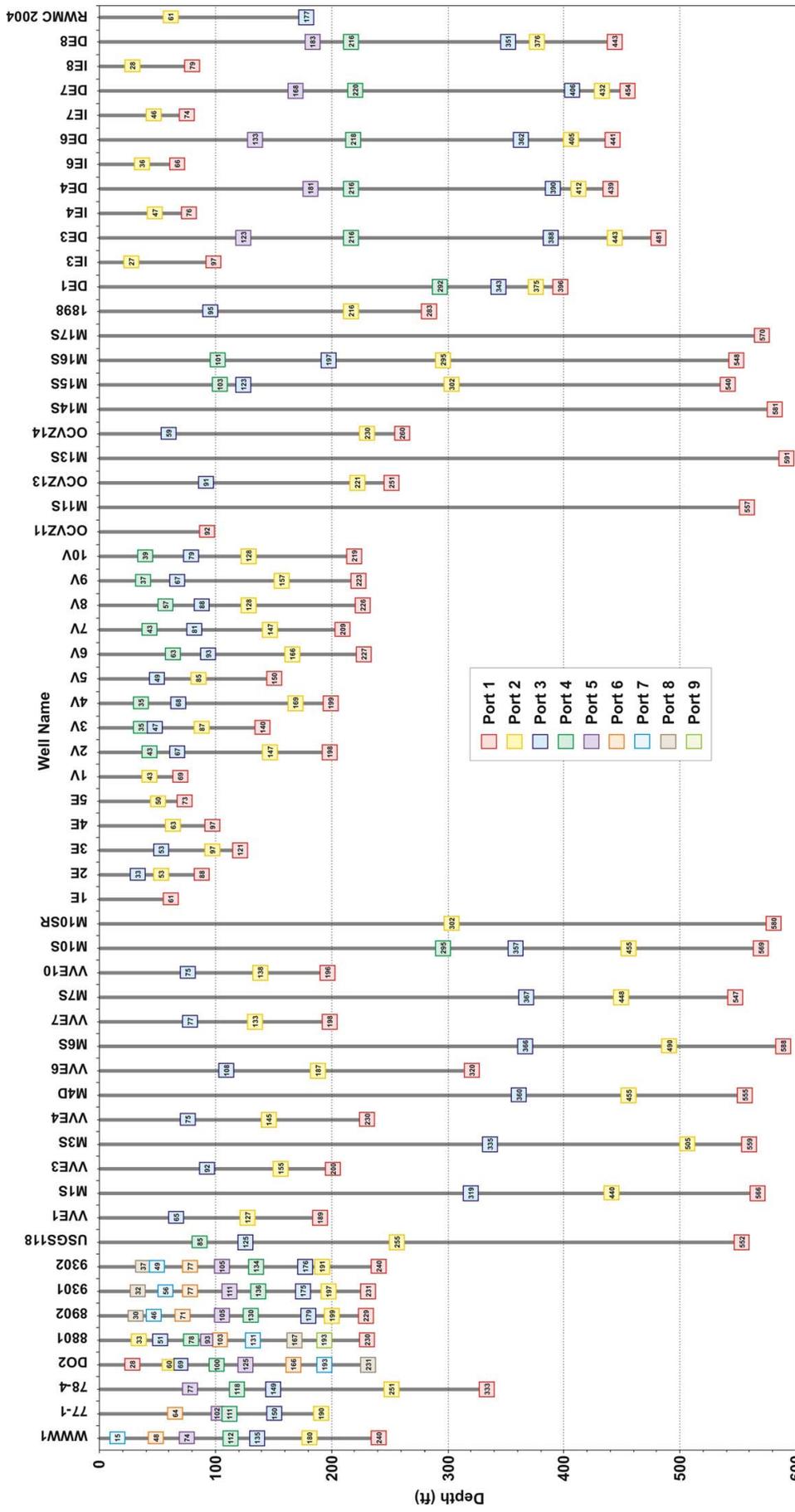
4.1.4.4 Vadose Zone Vapor Sampling. Vapor (i.e., soil gas) in the vadose zone is monitored using an extensive system of permanent vapor sampling ports located inside and outside the SDA. The ports are made of stainless steel tubing attached to the outside of well casings. Figure 4-45 shows the locations of wells with vapor sampling ports near the SDA, and Figure 4-46 shows depths of the ports. The port depths range from a minimum of 4.6 m (15 ft) in Well WWW1 to a maximum of 180.1 m (591 ft), just above the water table, in Well M13S. In total, 212 vapor sampling ports are installed in the vadose zone, not including the surficial sediment; however, only 174 are currently sampled.

The first vapor samples at the SDA were collected in 1988 and analyzed with a portable gas chromatograph. Since 1993, samples have been analyzed with a Brüel and Kjær photoacoustic multigas analyzer. The analyzer is capable of measuring the concentration of five compounds: carbon tetrachloride, chloroform, trichloroethylene, tetrachloroethylene, and 1,1,1-trichloroethane. Samples are currently collected monthly from wells in and immediately around the SDA and quarterly from wells farther away. Since 1999, the results have been reported semiannually by Operable Unit 7-08. The most recent VOC data report is by Housley (2005). The entire set of soil-gas data since 1992 is stored electronically. Data collected before 1992 are not used, except for historical identification of contaminants and qualitative analysis, because of concerns about quality and reliability (Izbicki 1992).

Soil-vapor concentrations are used to calibrate numerical transport models and to provide an indication of the effectiveness of the Operable Unit 7-08 remedial action (vapor vacuum extraction with treatment). Through numerical modeling, Operable Unit 7-08 has established remediation goals that consist of soil-vapor concentrations for carbon tetrachloride at different locations and depths in the vadose zone to preclude MCLs in the aquifer from being exceeded in the future (INL 2005). Soil-vapor concentrations are trended and compared to these remediation goals.

In addition to routine monitoring of vadose zone soil vapor, separate investigations of soil-vapor monitoring in the surficial sediment have been conducted. These include shallow soil-gas surveys in 1987, 1992, 1999, 2000, and 2001 and a one-time shallow well sampling activity in 1992. Sections 4.22 through 4.26 provide further detail.

4.1.4.5 Subsurface Soil Samples Collected While Drilling Lysimeter Well RWMC-2005. In April 2004, while drilling Lysimeter Well RWMC-2005 in the eastern end of the SDA (see Figure 2-19), radioactivity above background was detected in the drilling soil returns. Drilling was stopped, and three separate soil samples were collected from these returns and analyzed for radionuclides, anions and cations. Resulting data are presented in specific sections for each analyte that was detected.



Ports 3V-1, 3V-2, M10S-1, and M10S-2 are no longer operational
 Figure 4-46. Vapor sampling port depths and numbers.

4.1.5 Aquifer Data

Most aquifer data come from routine sampling by ICP and USGS around RWMC. Sixteen aquifer monitoring wells at the INL Site are monitored by ICP, and eight additional aquifer wells are monitored by USGS. One of the 16 RWMC aquifer monitoring wells managed by ICP (i.e., Well M10S) was taken out of service in 2001; however, because historical data are presented, repeated reference to 16 monitoring wells, instead of the current 15, appears throughout Section 4. Also, one of the eight aquifer monitoring wells managed by USGS (i.e., USGS-90) became nonoperational in 1999. Again, because historical USGS data are presented in this section, references are to eight USGS wells, instead of the current seven.

Figure 4-47 shows the locations of aquifer monitoring wells. The INL Site wells around RWMC were installed between 1992 and 2000. The USGS wells near RWMC were installed between 1971 and 1987.

Aquifer samples have been collected quarterly for many years; however, because years of monitoring data continued to show low and unchanging detection rates of contaminants, aquifer monitoring frequency was reduced to semiannually starting in August 2004 (Holdren and Broomfield 2004). Typically, the USGS and INL Oversight Program sample Wells M1S and M3S in conjunction with ICP. Recently, USGS began cosampling Wells M7S, M11S, M12S, M13S, and M14S with ICP. The USGS shares their analytical data with ICP and Idaho Department of Environmental Quality (DEQ). The ICP does not maintain records of INL Oversight Program analytical data. When detections occur, ICP, USGS, and the INL Oversight Program generally collaborate to confirm detections and to resolve analytical anomalies.

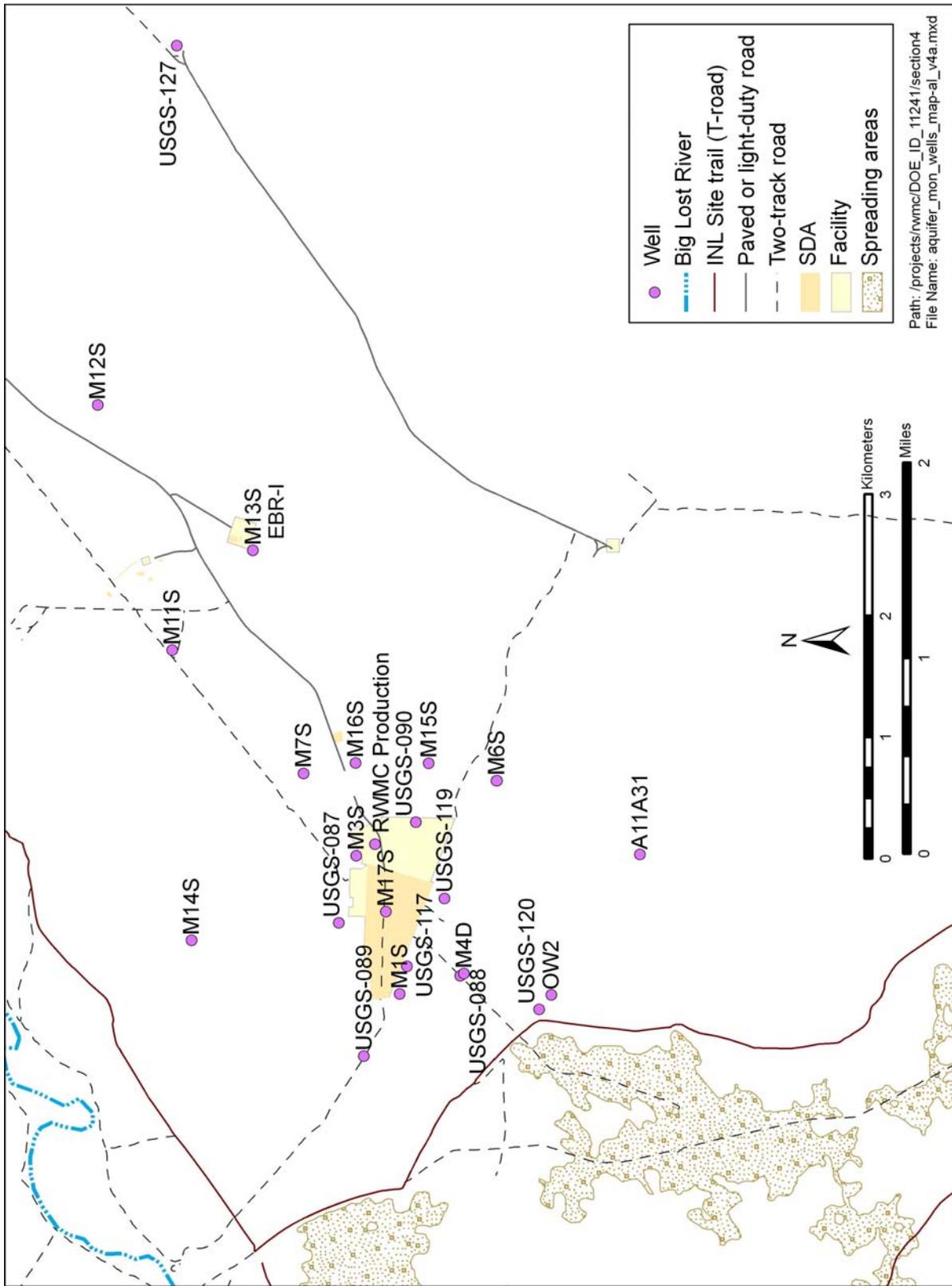


Figure 4-47. Radioactive Waste Management Complex aquifer monitoring wells.

4.1.6 Data Interpretation Considerations

Accurate interpretation of analytical data requires understanding limitations of analytical methods (e.g., impact of sample preparation and potential errors associated with measurements). Key issues affecting data interpretation for aquifer monitoring samples are discussed in the following sections.

4.1.6.1 Quality Assurance. Several quality assurance steps are implemented to ensure that aquifer data are the highest possible quality and that reported concentrations are representative of concentrations in the samples. Some quality assurance steps are not required for all analysis types. For example, some radionuclide analyses do not require matrix spikes and matrix spike duplicates. Quality assurance and quality control requirements for subcontracted laboratories are defined in Statement of Work for Analytical Services (ER-SOW-394). Quality assurance steps include the following:

- **Laboratory subcontracting**—Laboratories analyzing ICP samples undergo a rigorous evaluation, certification, qualification, and approval process. The laboratory must satisfy requirements of the national integrated contractor purchasing team and audits by the DOE national environmental monitoring and consolidated auditing program.
- **Intercomparison quality control performance program**—Subcontracted laboratories are required to routinely participate in quality control testing. Test results provide an indicator of a laboratory’s analytical abilities, performance, and reliability.
- **Performance evaluation sample**—Blind performance evaluation samples are prepared with each round of aquifer samples by a separate certified and authorized laboratory and submitted to the laboratory analyzing the ICP aquifer samples. Prepared samples are spiked with known concentrations to assess the accuracy and precision achieved by the laboratory for routine analytical measurements. Samples also are prepared to assess the analytical laboratory’s ability to report a nondetect result when an analyte is not present in the sample. If results do not agree with known concentrations, results for the affected analyte may be flagged as either questionable or rejected in accordance with data validation procedures.
- **Laboratory control sample**—The laboratory is required to prepare and analyze a laboratory control sample concurrently with each batch of aquifer samples. The control sample is a spike containing known quantities of the analyte of interest prepared by the laboratory, and the control sample is processed with each batch of field samples. This sample provides a means of measuring laboratory performance and accuracy of the analytical method. Results also are used to indicate whether the laboratory’s radiochemical procedure recovers the contaminant of interest. If the percent recovery for control samples is unsatisfactory, the remaining results for the affected analyte are flagged as either questionable or rejected in accordance with the percent recovery test criterion defined in data validation procedures.
- **Matrix spikes**—The laboratory is required to prepare a matrix spike and matrix-spike duplicate from an aliquot of an ICP aquifer sample. The aliquot is spiked by the laboratory with known quantities of pertinent analytes and is processed with each batch of aquifer samples. Results provide information about the effect of the sample matrix on sample preparation and analytical processes. If the percent recovery for the matrix spike is unsatisfactory, the remaining results for that particular analyte are flagged as either questionable or rejected in accordance with data validation procedures.

- **Method blank**—The laboratory is required to run a laboratory-generated blank sample (i.e., method blank) with each round and batch of aquifer samples. This test is used as a means of determining the existence and magnitude of contamination resulting from the sample preparation and analysis process (e.g., from chemical reagents, laboratory glassware, laboratory equipment, or instruments). If the method blank has detectable contamination, the remaining aquifer sample results for that particular analyte are flagged as either questionable or rejected, with consideration given to the magnitude of the difference between the blank result and the field sample results.
- **Laboratory duplicate**—The laboratory is required to prepare a laboratory-generated duplicate (i.e., split) from one of the ICP field samples. Duplicate analyses can indicate analytical variability and laboratory precision or the homogeneity of the sample. Duplicate results must satisfy relative percent difference criteria and mean-difference test criteria. If criteria are not satisfied, either the duplicate sample results or the rest of the aquifer sample results for that particular analyte are flagged as either questionable or rejected in accordance with the mean difference test criterion defined in data validation procedures, which depends on the sample matrix and known sample homogeneity for that particular matrix.
- **Field duplicate**—A field duplicate is a second sample collected in the field from the same well as each quarterly round of samples. The field duplicate provides information about the representativeness, homogeneity, and variances associated with each field sampling and monitoring event. If the relative percent difference and mean-difference test criteria are not satisfied, the rest of the aquifer sample results or only the duplicate sample results (for that particular analyte) are flagged as questionable or rejected in accordance with the mean-difference test criterion defined in data validation procedures, which depends on the sample matrix and known sample homogeneity for the particular matrix.
- **Field blank**—A field blank is a container of clean deionized water that is prepared and collected in the field. The field blank container accompanies the samplers throughout the entire sampling event. At each wellhead, the container is opened, and a small amount of the clean deionized water is poured into the blank container. The field blank is submitted to the laboratory and analyzed with each set of aquifer samples. The field blank provides information that is used to assess whether any sample contamination was introduced by field operations and conditions. If the field blank has detectable contamination, the rest of the aquifer samples for the detected contaminant are flagged as questionable or rejected, depending on the magnitude of the difference between the blank result and the field sample results. Mean-difference test criteria are defined in data validation procedures.
- **Equipment rinsate**—Water is poured over, around, and through the sampling equipment after use. This sample is analyzed with each set of aquifer samples to assess whether sampling equipment compromise analytical results. If the rinsate blank has detectable contamination, the remaining aquifer samples for the detected analyte are flagged as either questionable or rejected, depending on the magnitude of the difference between the blank result and the field sample results. The mean difference test criteria are defined in the data validation procedures.
- **Reanalysis**—When an aquifer sample contains a concentration of a radionuclide greater than three times the reported 1σ uncertainty (see Section 4.1.6.2), the laboratory is required to pull another aliquot from the sample container and analyze it. Reanalysis of the same sample can confirm detection and also can provide information about sample inhomogeneity. Both results, the original and the reanalysis, are reported. If the reanalysis result is a nondetect, the sample result is not a confirmed detection.

- **Laboratory performance evaluation program**—The performance of each subcontracted laboratory using various performance indicators is continually assessed and tracked by ICP using a formalized and documented plan. This program ensures that ICP sample analyses are performed by the best-performing subcontracted laboratories.

In addition to the quality assurance measures listed above, which are performed by the subcontracted laboratories, some quality assurance is also garnered from USGS sampling. The USGS routinely collects samples from a subset of wells that are simultaneously sampled by ICP. The USGS validates their results and provides those validations to ICP. The two sets are compared to help assess and confirm low-level detections.

4.1.6.2 Radiological Uncertainty. When radioactive materials decay, they emit alpha particles, beta particles, or photons (i.e., x-rays and gamma rays). Emissions from radioactive atoms are random and erratic and can be difficult to measure precisely at low activity levels. The rate of radioactive decay is proportional to the amount of radioactive material present, which depends on the particular radionuclide present and its associated radioactive decay constant (i.e., the number of radioactive atoms that decay per unit of time). If the rate of radioactive decay is fast (i.e., the radionuclide has a high specific activity), then many emissions occur per unit time, and the radioisotope is characterized with a short half-life. Conversely, if the specific activity is low, few emissions occur, and the radioisotope is characterized with a long half-life. The lower the specific activity, the longer the half-life and the higher the measurement uncertainty can become. For typical environmental-level radioactivity, where emissions typically occur less frequently, a much longer measurement interval is required to obtain an accurate count of the emissions and quantify the amount of radioactivity present.

Radiological uncertainty is a reported value that accompanies the reported concentration and also follows a known probability distribution. The uncertainty value reported with each measured result is a total of all the recognized errors in the entire analytical process and is referred to as the total propagated uncertainty or, more recently, as the combined standard uncertainty. The laboratory-reported uncertainty for each sample is given by the standard deviation (σ). All laboratories subcontracted through ICP are required to report uncertainties at the 1σ confidence level. Radioanalytical results are reported as a measured concentration plus or minus its uncertainty. The 68.3% confidence interval for a value is formed by plus or minus 1σ . Similarly, $\pm 2\sigma$ defines the 95.4% confidence interval, while $\pm 3\sigma$ defines the 99.7% confidence interval.

The result from a sample measurement is declared as (1) a nondetection, (2) a statistical detection, or (3) a positive detection, depending on its magnitude relative to its uncertainty. If the measured value is between 2σ and 3σ , it is a statistical detection and qualified with a J validation flag to indicate the detections are uncertain and should be used only as estimates. If the measured value is greater than the sample-specific minimum detectable activity and is more than three times greater than its uncertainty, it is a positive detection. Otherwise, the result is a nondetection. Data quality associated with statistical detections (i.e., $2\sigma < X \leq 3\sigma$) does not satisfy criteria for reportable detections; however, statistical detections are evaluated closely for early indication of developing trends or sudden changes.

Before 1998, “Radioanalytical Data Validation” (TPR-80) defined detection of a radionuclide based on 2σ instead of the currently applied 3σ . After comparing detection standards used by other agencies (i.e., USGS and DEQ), detection criteria for ICP were changed to greater than the minimum detectable activity and greater than 3σ to be consistent with results reported by other agencies. All results identified as positive detections in this remedial investigation were assessed with the 3σ criterion.

The minimum detectable activity is defined as the minimum amount of radioactivity in a sample that can be detected with confidence given a defined set of background, sample, instrument, analytical, and measurement conditions. The minimum detectable activity is a probabilistic approach to determine whether radioactive material is present in a sample. The minimum detectable activity is derived from the sample measurement and represents the 95% probability that radioactivity is present in a sample. The minimum detectable activity is defined as $2.71 + 4.65B^{1/2}$, where B is the ambient background at the instrument, and 2.71 and 4.65 are probability-based values. This equation was derived by Currie (1968) and is a standard method for computing the minimum detectable activity throughout the analytical industry. All laboratories subcontracted through ICP Sample and Analysis Management use this method of computing the minimum detectable activity.

4.1.6.3 Nuclear Logging Data. Nuclear logging tools were deployed in the SDA to acquire in situ information about subsurface conditions within the waste for several purposes, including (1) depicting waste types identified from waste inventory records, (2) identifying areas with relatively high concentrations of radionuclides and VOCs to choose locations for Type B probes, and (3) identifying target waste suitable for pilot remediation studies. Unique combinations of various radionuclides, trends of the radionuclides, or unique characteristics identified by Type A nuclear logging were used to identify waste streams and locations for Type B probes. Specific information obtained from the subsurface data collected during the logging campaigns includes the following:

- Clearly delineated thicknesses of overburden, underburden, and waste-bearing zones were determined.
- Specific waste types (e.g., Pu-239-bearing graphite mold waste, Series 741 and 743 sludge, depleted uranium, and enriched uranium) were identified based on measured characteristics of the radionuclide and elemental (chlorine) mixtures of the waste media. Results were consistent with waste profile information available from inventory records.
- Type A probe nuclear logging allowed Type B probes to be placed into specific waste types of interest.

Although Type A probes and the tools employed therein provided a large, high-quality data set, the data were primarily qualitative. The uncertainty associated with heterogeneity of the waste zone overwhelmed attempts at quantitative estimates from the data sets (particularly the passive gamma-ray and the n-gamma logging data) and required significant computational efforts (Jewell, Reber, and Hertzog 2002). Nonetheless, the logging data reveal useful information that inventory records cannot provide about the physical, chemical, and radiological conditions at specific locations.

4.1.6.4 Early 1970s Data. In the early 1970s, the U.S. Atomic Energy Commission (predecessor to DOE) sponsored a hydrogeologic study of the RWMC area to determine whether waste buried in the SDA threatened the quality of the Snake River Plain Aquifer and constructed wells to monitor the groundwater near RWMC. The first study was conducted by the USGS in 1971 to 1972 (Barraclough et al. 1976) and incorporated sampling of sediment, cores, and water.

Ten wells were drilled for this study, and many of the collected cores and samples of sediment, aquifer, and perched water contained numerous inexplicable radionuclide detections. Results of this study were published by Barraclough et al. (1976); however, though the authors concluded that transport of radionuclides had occurred, they also suggested the possibility that radionuclides could have been artificially introduced by the drilling methods (i.e., cable-tool method and dry air rotary drill), the sampling techniques (e.g., thief sampler), or that radionuclide detections were the result of laboratory error. Therefore, conclusions were questioned.

A second study, sponsored by DOE (then the Energy Research and Development Administration), was conducted in 1975 to substantiate the conclusions and suspicions of the 1971 to 1972 investigation. Wells were drilled near those of the first study, and special precautions were taken to prevent cross contamination during drilling and sample handling. Nearly all results of radionuclide analyses from this study were nondetections, and the conclusions (Burgus and Maestas 1976; DOE-ID 1983) contradicted those of the first study. This introduced considerable doubt as to whether radionuclide transport had actually occurred.

Other drilling campaigns followed, including installing additional aquifer monitoring wells at RWMC. Detections near the limits of detection occurred sporadically in aquifer samples for a year or two after the USGS monitoring wells were installed. After 1974, radionuclide detections ceased. Data collected in the 30 years following the early 1970s suggest that contamination is not widespread within and outside RWMC in either the vadose zone or the aquifer.

Unfortunately, analytical data from the early 1970s cannot be properly validated because the necessary analytical information was not archived. Therefore, the 1971 to 1974 data remain questionable. Though some degree of uncertainty will always be associated with the issue of sample contamination during well drilling, improved techniques were applied to prevent sample contamination in each subsequent well-drilling activity. In 1978, the sampling procedure was changed to include split samples that were analyzed independently of one another (Dames & Moore 1994). Protocol required that positive results had to be obtained in both samples (i.e., splits) to confirm the presence of radionuclides. In the 1970s, results were considered positive if they exceeded the 2σ (95%) confidence interval (Dames & Moore 1994). In addition, criteria for reporting positive detections also have tightened. In the 1980s, a 3σ (99.7%) detection criterion replaced the 2σ used previously; however, some data interpreters continued to report 2σ results as positive detections. Thus, positive detections were defined with inconsistent protocol. In 1998, the radioanalytical data validation protocol officially adopted and implemented the 3σ confidence interval to define a positive detection (see Section 4.1.6.2). This criterion was consistent with that applied by USGS, DEQ, and INL Oversight Program.

Dames & Moore (1994) compiled and statistically reanalyzed most of the subsurface drilling and coring investigation data collected between 1971 and 1987. Core data presented in this report include data from sampling campaigns from 1971 to 2003.

The analysis of water samples collected from the deep wells outside RWMC in 1971 to 1974 showed trace quantities of waste radionuclides in some samples from all four wells. According to Barraclough et al. (1976), “. . .the drilling and well-construction techniques, the water sample-collection methods, and the uniform distribution of positive results in all four wells suggest artificial contamination. Though these data could be the result of some waste migration to the aquifer, they are considered inconclusive evidence at this time.” Barraclough et al. (1976) hypothesize that the static thief sampler is implicated in some of the contaminated water samples.

Samples from Well USGS-88 in 1971 to 1972 contained anomalous concentrations of dissolved solids, magnesium, hydroxide, and high pH, suggesting cement constituents in the well. In addition, significant radionuclides were detected in samples from Wells USGS-89 and USGS-90; these detections were not confirmed by later sampling, indicating artificial contamination in these samples. Barraclough et al. (1976) concluded that data from the 1971 to 1974 sampling were unreliable. Dedicated submersible pumps were installed in Wells USGS-87, -88, -89, and -90 in October 1974, and sampling methods were developed that included purging three well volumes from the wells before collecting the sample. After implementing these changes, radionuclides in the wells outside RWMC were not detected.

4.1.6.5 Lysimeter Data. Lysimeters are used to obtain samples of soil moisture from unsaturated sediment or rock. The sample is drawn through a porous membrane or cup on the end of the lysimeter, which is usually imbedded in a silica-flour backfill within the vadose zone material. Organic compounds generally are lost during the lysimeter sampling process (Wood et al. 1981). Early researchers noted that a ceramic membrane could interact and influence the chemistry of the material being sampled. Studies of soil water containing common anions, cations, and nutrients demonstrated that porous membranes could modify the geochemistry of fluids by either sorbing or adding ions (Haines, Wade, and Topp 1982; Lord and Shepherd 1993). Typically, the chemistry is affected by sorption of ions on the membrane, but several investigations have noted the addition of several trace constituents.

Few data relate to sampling for radionuclides with suction lysimeters. A laboratory partitioning study was conducted to evaluate the influence of the silica flour backfill and the porous cup in the suction lysimeters on sorption of selected radionuclides (Fjeld, Coates, and Elzerman 2000). The study suggests that Sr-85 and U-233 are not significantly attenuated, while Am-241 and Pu 239(IV) are attenuated by contact with the silica flour used to backfill the instruments. Tests were conducted on the sorption of radionuclides contained in simulated groundwater while being passed through the ceramic porous membrane of a suction lysimeter. After 5 hours of contact with the porous cup, approximately 99.9% of americium, 89% of plutonium, 33% of neptunium, and 3% of uranium were retained in the ceramic lysimeters. These data indicate the soil moisture collected in porous ceramic suction lysimeters will have lower concentrations of some radionuclides than soil moisture in the surrounding undisturbed geologic media within the first 5 hours of sampling. Most lysimeters installed before 1999 had the porous ceramic cup.

Suction lysimeters with porous stainless steel were installed in the B-C and C-D interbeds in 1999 and 2000. Stainless steel is less reactive than ceramic membranes but may contribute trace metal to the samples.